INVESTIGATION OF SORTING TECHNOLOGY TO REMOVE HARD PEBBLES AND RECOVER COPPER BEARING ROCKS FROM AN AUTOGENOUS MILLING CIRCUIT

K Seerane
Rio Tinto Group

G Rech
CommodasUltrasort

1 Introduction of Ore Sorting into an Autogenous Mill Circuit

Palabora mining company operates two fully autogenous milling circuits (AG mills). These modular units are each fed by a dedicated ROM stockpile supplied by the underground mine. Historically the AG milling circuit has operated very well and achieved the required production levels that are required for the open pit mine. During the open pit mining operations the dolerite was segregated from the ore and very little dolerite was fed to the AG mills. However in the underground operations selective mining and segregation of dolerite is not possible and this material, containing significant amounts of dolerite will be fed to the AG mills. In addition the feed to the AG mills has changed from the traditional foskorite ore to transgressive/banded carbonatite ore which constitutes the major ore type underground.

A considerable amount of test work, including computer simulations, was undertaken to establish the optimum design for the grinding circuit configuration for the underground material and to counteract the negative effects of the increased dolerite levels in the feed. The feed to the AG mills contains an average dolerite content of 12%.

Dolerite has a work index of 24 Kwh/tonne compared to 13 Kwh/tonne for the ore. This has a substantial impact on the grinding performance of the AG mills. Dolerite with its high work index does not grind at the same rate as the rest of the ores, and consequently it builds up as a high circulating load in the circuit. The AG mills eventually become saturated with the fine dolerite which upset the ratio of coarse grinding media and fines causing a reduction in the milling efficiency and ultimately the throughput.

Through optimisation work, the AG mills have each demonstrated a maximum milling rate of 800 tph for a full shift which is 200 tph higher than the normal operating rate of 600 tph. Part of the optimization work involved bleeding off the high dolerite (55 to 65%) circulating pebbles from the AG mills. This process of tapping off helps to create extra milling capacity for fresh feed. Test work also revealed that for every tonne of dolerite removed from the AG mill circuit there will be 7 to 8 tonnes of incremental fresh feed. This benefit forms the basis for justification a dolerite sorter requirement in the AG mill circuit and it constitutes a strong business case.
2 Primary function of the sorter inside the AG mill process flow

2.1 Current operating philosophy (without a sorter)

The AG mills circuit operates at normal rate of 600 tph with the minimum run rate of 500 tph and a maximum of 800 tph depending on the dolerite content and the PSD of the feed. Dolerite in the feed, depending on mining plans and draw compliance, varies from 6 to 13%. The lower the dolerite content in feed the higher the AG mill throughput and vice versa. When the mill conditions become upset (particularly the mill power and bearing pressure) such that the throughput is adversely affected due to high dolerite level in the feed, the circulating load will be tapped off as a strategy to increase milling rates. The problem with the tap off strategy is that 4% of recoverable copper metal in feed is lost. To recover this copper would require an additional reprocessing stage which will incur extra haulage and processing costs.
2.2 Proposed operating philosophy (with a sorter) 
AG mill discharge screen oversize pebbles, +15mm - 60mm, will be fed to the sorter which will selectively remove and put dolerite to a reject stream while the product stream is circulated back to the mill for further grinding. The product stream will be comprised of magnetite and carbonatite. The reject stream will be piled up on a dedicated stockpile for disposal.
3 Ore Sorters

Sorting material by hand to remove a wanted product from waste material has been practiced throughout history. Automated sorters have been developed and used in the mining industry since the beginning of the 20th century (1). The principle has not changed but the sensing techniques, mechanical handling and separation systems have rapidly advanced over the last 10 years.

Modern sensor based ore sorters work on a rock by rock basis. They rely on the sensing system being able to distinguish each rock that passes through the sorter, and provide information on that rock that can be used by the electronics processing system to establish if it is wanted product or waste, after which the ejection system is used to divert that rock into a different ore stream as required.

Ore is fed into the sorter using a feeder or belt system to ensure a monolayer of stable particles are presented to the sensing system which sends data characterising each rock to the electronics. The electronics processes this data and discriminates the ore from the waste. This information is then passed onto the ejectors that separate the feed into an accept and reject stream using blasts of compressed air to change the flight trajectory of selected rocks to fall below a dividing plate. These rocks form a different output stream to those not ejected.

Sorters can comprise of a belt system or a chute system with particles being moved through or falling through the sensing and ejection zones respectively.

An ore sorter can be broken down into four effective parts. The mechanical handling system, sensing system, processing electronics and the ejection system. If any one of these parts is not optimised the efficiency of the sort will be affected.

![Figure 4: Schematic representation of ore sorter for material below 75mm](image)
3.1 Mechanical Handling
The pressure on modern sorters is for higher throughputs in an effort to simplify the plant and maintenance of the sorting system and reduce the capital investment and running costs. Higher throughputs can be achieved by:

3.1.1 Turning up the feed rate
Higher feed rates will result in larger throughputs but will also result in higher belt/chute occupancy where more rocks are in contact with one another. These rocks present a challenge for the sensing system to distinguish. Although advanced processing system may be able to extrapolate the shape of clustered rocks to identify the individual particles, the ejection system is not able to separate a clustered rock from its immediate neighbour without affecting the trajectory of both particles.

This results in a strong relationship between the belt/chute occupancy and the accuracy of the sort, with an upper limit that results in significant errors once crossed.

3.1.2 Wider machines
A higher throughput can be achieved with a constant belt/chute occupancy and wider machines. The sorting width is however restricted by the limitations to the size and complexity of the sensing and ejection systems and the serviceability of the machine.

3.1.3 Faster moving rocks
Faster belt speeds or faster falling rocks require more accurate, faster ejection systems that run at higher pressures, faster electronics and very stable belt or feed systems. At very high speeds even the aerodynamics of the particles have to be taken into account as they can sometimes result in particles lifting off the belt or variations of the natural trajectories of the particles that make ejection more difficult.

3.1.4 Sorting larger rocks
Sensing and ejections systems in sorters work across the width of the sorter and have belt/chute area occupancy limitations described in 3.1.1. With some modern sorters taking up to 300mm rocks, sorting larger material results in a higher throughput for the same belt/chute occupancy. There are upper limits to the size range that can be sorted and this is affected by; the sorters mechanical handling system, the liberation size of the ore and the crushing, screening and processing system of the mine.

These four factors need to be balanced to ensure that the maximum throughput of the sorter is achieved while maintaining the accuracy of the separation.

3.2 Sensing System
Sensing systems span the entire electromagnetic spectrum to ensure that any measurable difference between ore and waste can be characterised and used as a separation criteria.
The sensing system generally scans across the sort width and is placed as close to the ejection system as possible to maximise the accuracy of the sort. These sensing systems need to be fast as well as accurate, scanning the belt thousands of times per second to ensure the each particle is individually mapped and characterised.

With such a variety of sensors being available a testwork programme is often required to establish which of the sensing systems is the most appropriate for an ore body. As an initial study a selection of a few hundred rock samples is analysed in a laboratory environment where sensor data from each system is collected for each sample and this compared to their assay grade. In this way the sensors are compared to see which would result in the most effective sort.

Many of the sensing systems are well established sorting particular ore types. This is particularly true for the optical systems. In these situations a few tonnes of ore can be run through a machine in a test facility at the required throughput to establish the upgrade potential of the ore. This information can then be used for the economic model or to evaluate where in the process flow the sorter should be placed.

3.3 Electronics
Historically most sorters used custom built dedicated parallel processors to ensure that the data was processed within the faction of a second that the particle takes to travel between the sensor and ejectors (4).
The exponential increase in the power of modern computing systems has brought these up to the point where they can be used in some sorting applications. The very highest speed systems and those that require intense data processing are still mostly done by the custom parallel processors but the flexibility and ease of programming computer based sorters has seen an increase in their use.

It is a common misconception that the processing system is the limiting factor in the amount of ore that can be sorted per second. This is not usually the case as the speed of the sensor, stability of the throughput and physical separation systems usually form the limiting factors.

3.4 Ejection
With rocks moving through the sorter at up to 6m/s the speed and resolution of the ejectors has a dramatic effect on the efficiency of the sort. Commercially available ejection systems, including off-the-shelf air ejectors and flapper paddle systems have response times in the tens of milliseconds at best. A 20ms ejector with a particle travelling at 6m/s will result in a 120mm ejection. By ensuring that there are no neighbouring particles within this spacing results in a reduced throughput.

High pressure custom designed ejection systems with high flow characteristics and a response time of 2ms have resulted in a step change in the accuracy of the ejection system increasing the throughput of the sorter.

These systems are designed for the mining industry with significantly lower air filtering requirements and reduced maintenance.

4 Using Multiple Sensors on Palabora Mill Scats
Another advantage of having a wide range of sensing systems available is that they can be used in combination to provide custom sorting solutions. An example of this is the work done at one the CommodasUltrasort test facilities in Sydney Australia in January 2011 on material from the mill stock pile from Palabora mine.
The figure below outlines the optical difference between three types of material; the copper bearing carbonatite (light coloured), the magnetite (dark coloured), and the hard unwanted dolerite (dark coloured). Both the carbonatite and the magnetite are wanted ores and so a combination of optical sensing, used to differentiate between the lighter carbonatite and the darker magnetite and dolerite, and electromagnetic sensing used to differentiate between the magnetite and the dolerite were used.

![Figure 7: White carbonite, darker magnetite and dolerite](image)

<table>
<thead>
<tr>
<th>Ore</th>
<th>Optical (light/white)</th>
<th>Electromagnetic Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonatite</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Magnetite</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Dolerite</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

Using the logic shown in Table 1 above the sorter was used to sort the material as show below:
Figure 8: Test work flow sheet

With this system the client can choose to create a carbonatite stream and then rerun the magnetite/dolerite through the same sorter again to create the 2 products and 1 waste stream as shown above or create a carbonatite/magnetite stream and dolerite waste in one pass if required.

Figure 9: Optical sorting producing highly efficient separation of light and dark particles
The sorter houses both the EM and optical sensor simultaneously and can process the data for both sensors but the ejections system is designed to produce only two output streams. Ejection systems have been developed to produce three streams in one pass but these systems are very inaccurate especially with fast moving particles. To produce three streams two sorters are either put in series or the material is passed through the same sorter twice.

Figure 10: Cu grade of head feed, concentrate and tails for each of the size fractions tested
As can be seen in Figure 12 a significant increase in the grade of the copper was achieved for all the size fractions tested. Figure 13 shows the high copper retention with significant mass reduction. It is recommended that the increase between min and max particle size should not exceed 3:1 as can be seen in the +19-75mm size fraction this does result in a reduction in the efficiency of the sort.

Although a total iron content of the different streams was ascertained by laboratory assay, this total iron content does not discriminate between the useful magnetite and iron contained in the dolerite. Further work needs to be done to establish the magnetite recovery and upgrade.

Table 2: Test unit throughputs for different size fractions

<table>
<thead>
<tr>
<th>Size Fraction (mm)</th>
<th>Throughput (t/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+16-25</td>
<td>27</td>
</tr>
<tr>
<td>+19-40</td>
<td>37</td>
</tr>
<tr>
<td>+40-75</td>
<td>70</td>
</tr>
<tr>
<td>+19-75</td>
<td>45</td>
</tr>
</tbody>
</table>

Table 2 above shows the throughputs for the different size fractions. As described in 3.1.4 the larger size fractions have higher throughputs. With only a few hundred kilograms of feed per test run the ramp up and down time of the sorter becomes significant making these measurements only approximate values. With field based system many clients have exceeded these throughputs with only minor reductions in accuracy.
The ability of the sorter to achieve significant increase in the copper grade while removing the unwanted hard dolerite from the mill circuit demonstrates that the sorter can produce a quality product at high throughputs.

5 The future of ore sorting at Palabora primary and secondary benefits

- With the removal of dolerite from the AG mills capacity will be created in the mills for fresh feed which will in turn increase the throughput, thus more copper metal output from the AG mills. As a result of incremental throughput, there will be significant reduction of underground ore that normally overflows to the third underground pad since most of this material will be handled by the AG mills. The stockpile and its respective conventional milling and flotation circuits will be available for other process opportunities.
- There is a potential savings on cost for reprocessing tap off material because the reject stream from the sorter will not require any further work as the material will predominantly contain dolerite which is barren.

5.1 Palabora’s position with sorting project

Over the past eleven years Palabora has stockpiled more than 600kt of tap off pebbles from the AG mills with an average grade of 0.25% copper. The sorter technology will be tested on this historic pile and a full plant scale implementation will be considered once the success criteria have been fulfilled.

6 Acknowledgements

The test work was carried out at the CommodasUltrasort Pilot test facility in Australia, supported by the Rio Tinto Technology and Innovation (T&I) group and Palabora Mining Company. Grateful thanks are due to the CommodasUltrasort staff for making the facilities available, Rio Tinto T&I for the technical support and Palabora Mining Company (Concentrator Team) for ensuring that the samples are available for the work. In addition, special recognition is extended to Dr. Percy Condori, Jason Winnet, B. Songo, E.Katsande and R. Moagi for fruitful discussions and critically reviewing this document.

7 References

The Author

Gavin Rech, Engineering Physicist, CommodasUltrasort

**Education:** BSc (Hons.) Physics, University of the Witwatersrand, South Africa. Current Position: Technical Manager Sensors and Physics, CommodasUltrasort pty ltd, designing of ore sensing and sorting systems.

**Experience:** Over eight years experience in the analysis of geophysics and mineral data and systems, including radar, x-ray, resistivity, conductivity and radiometry in Australia and UK.